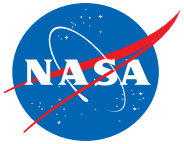


# Fast Response Engine Research

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2012 PCD Workshop

Cleveland, Ohio

# Overview

- Why do we want faster engine response?
- Challenge
- Approaches
  - Controller Gain Modification
  - Risk-Based Limit Modifications
  - High Speed Idle
- Conclusions

# The Case for Faster Engine Response

- Use of engines can increase the likelihood of recovering the aircraft
- From Dryden studies after UA232: engines are too slow

# Challenges

- Engine behavior is highly non-linear with different response based on:
  - Initial power setting and final power setting
  - Operating condition (altitude, Mach, ambient temp)
  - Engine age
- Regulatory/certification challenges

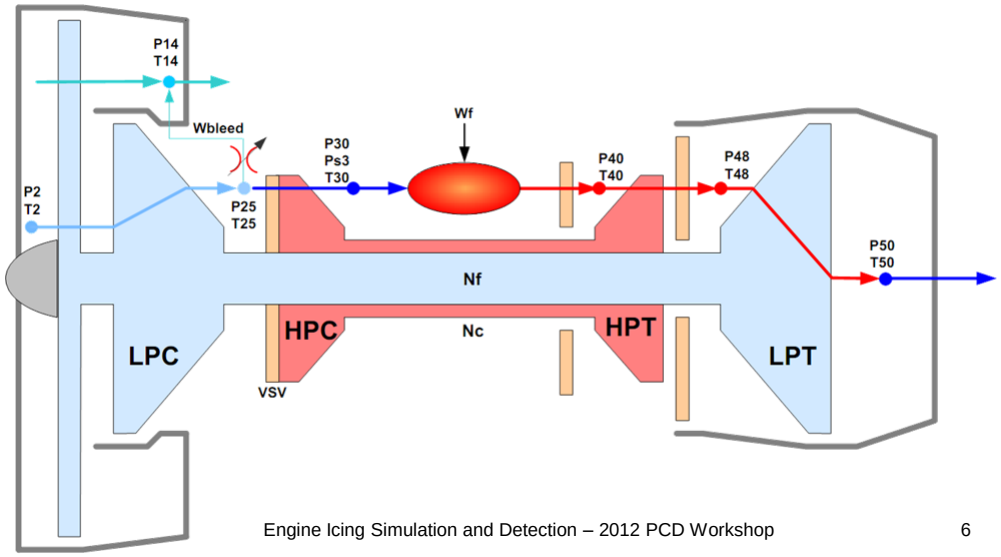
- Using the engine in an “atypical” manner presents risk of engine failure (either immediate or gradual)

# GRC Approaches to Faster Response

- Requirements: Must not change the basic architecture of the existing control system
- Use a number of approaches to improve response
  - Increase controller gain – small throttle changes
  - Relax engine limits – large throttle changes, edge of envelope operation
  - Change engine operating point using actuators off-nominally
- C-MAPSS40k used as development platform

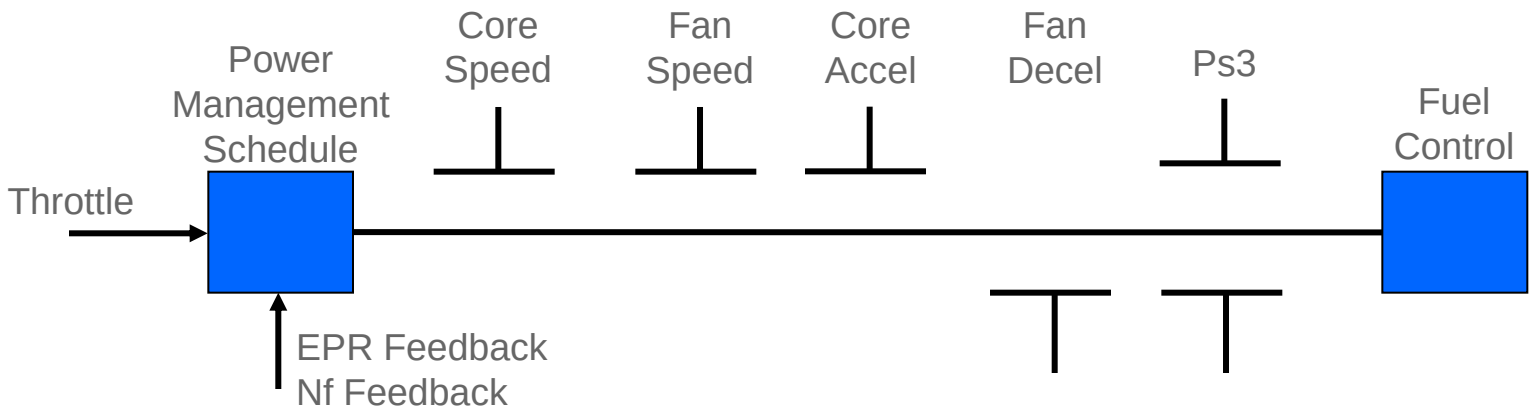
# C-MAPSS40k

- C-MAPSS40k engine simulation
  - Commercial 40,000lbf thrust, high-bypass turbofan engine
  - Physics-based model
  - Realistic engine control system
  - Written in MATLAB/Simulink
  - Modular design



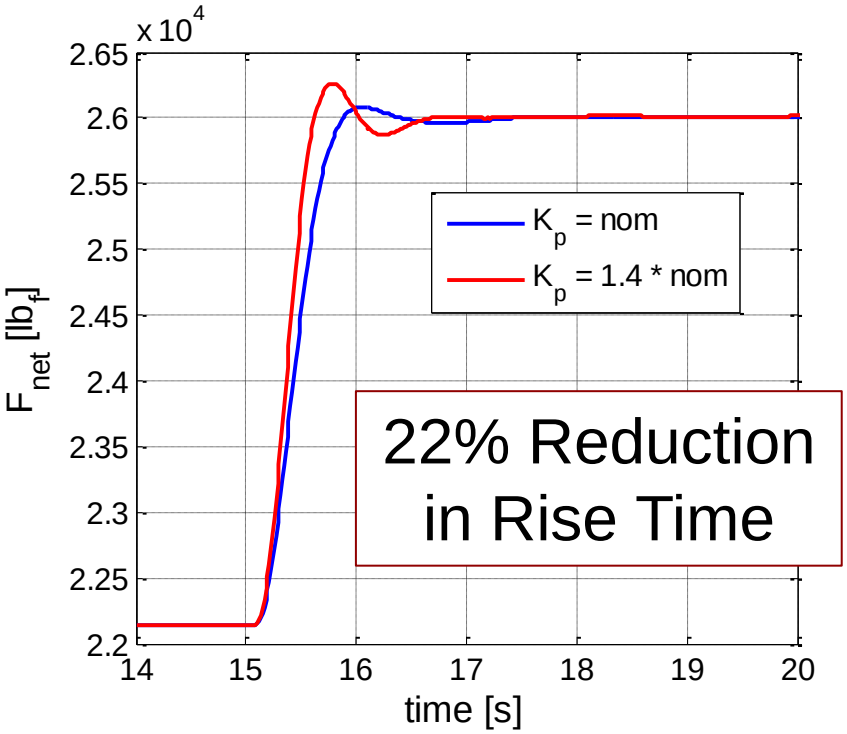
# Engine Control System

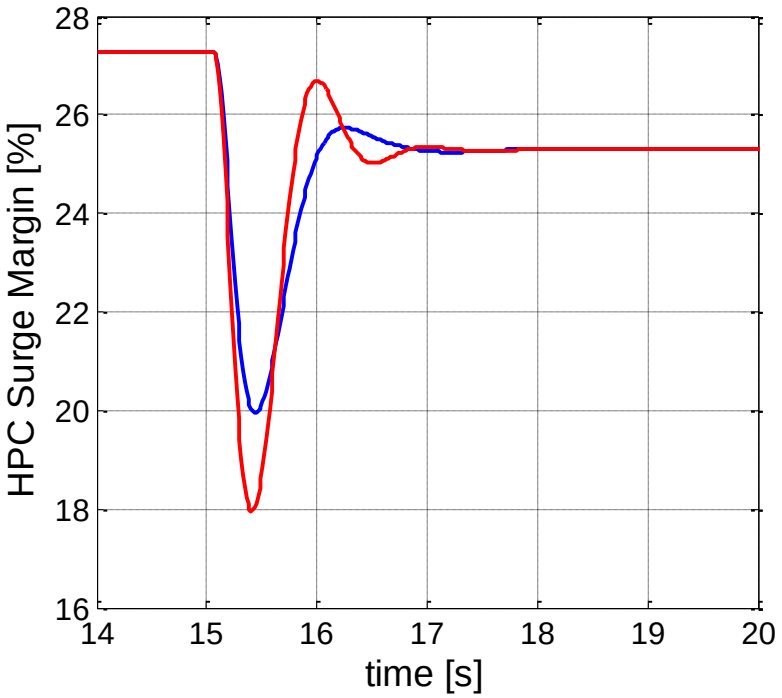
- Power Management
  - Responsible for holding current power level (EPR or Nf)
- Protection Logic
  - Responsible for ensuring safe operation
  - Adjusts Fuel Flow to ensure limits are observed



# Controller Gain Modification

- Changing the setpoint controller's gain will improve response during small transients
- Increase in gain reduces stability margins
- Marginal impact on HPC Surge Margin



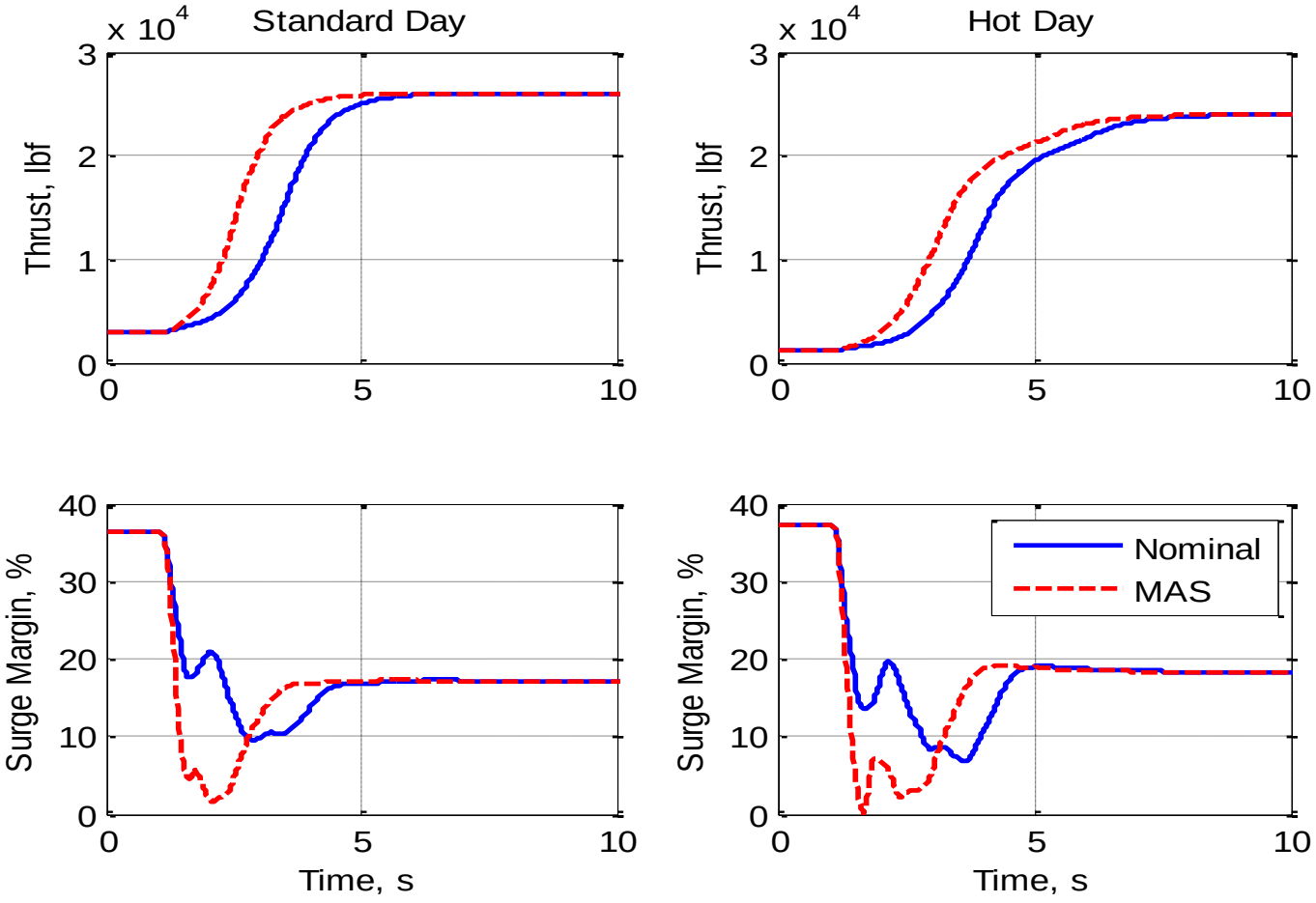



# Risk-Based Limit Modification

- Primary concern during large throttle transients is compressor surge margin
- Can “relax” the acceleration limit
  - Improved response and decrease in surge margin
- Is it worth it?
  - New engines have “extra” SM
  - SM changes based on environment
- Can minimize the risk with increased knowledge of current state, but any change will increase risk of surge
  - Must choose an acceptable risk that balances chance of engine failure with aircraft survivability

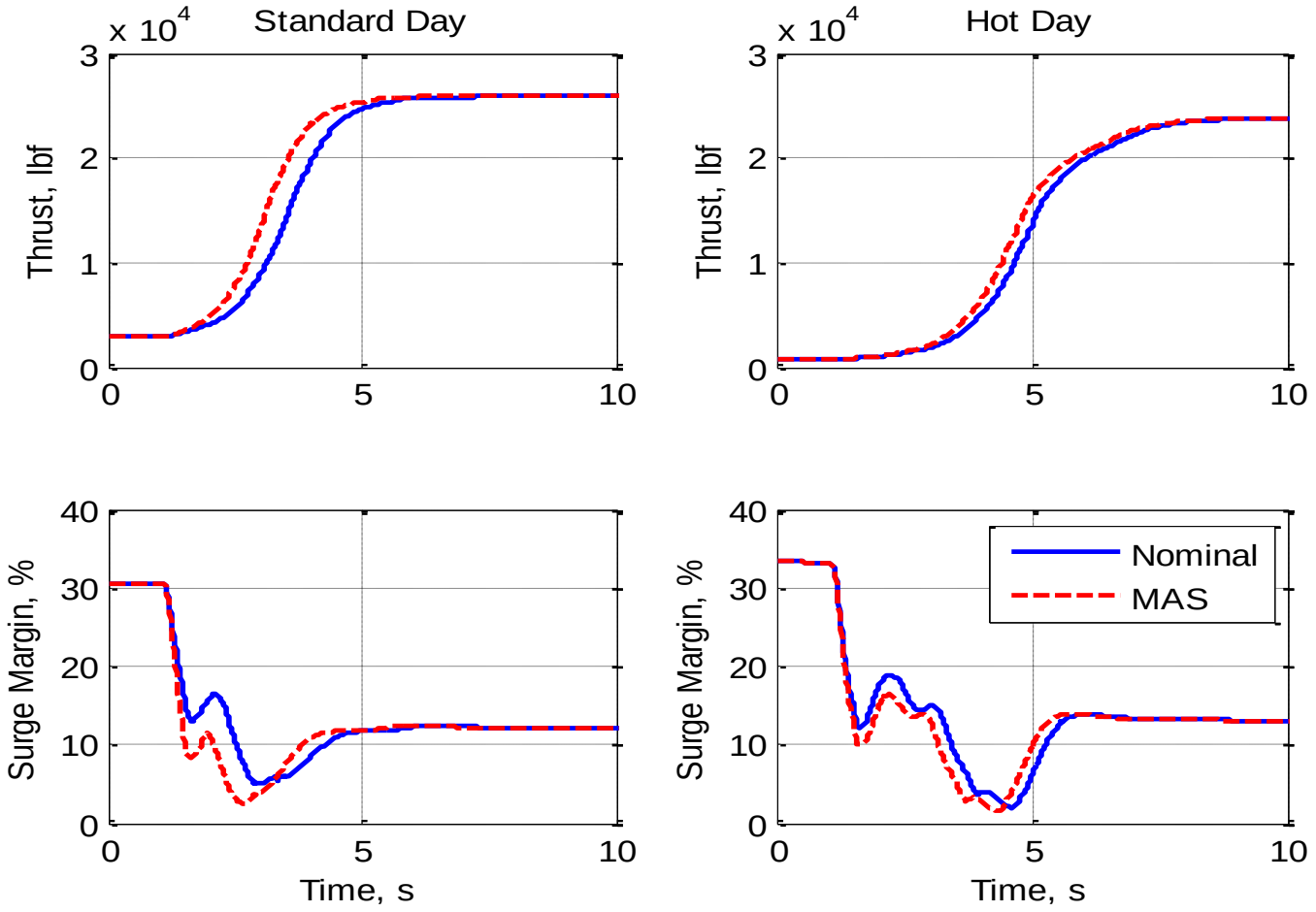
# Risk-Based Limit Modification

- Response of a new engine to full throttle change



# Risk-Based Limit Modification

- Response of an old engine to full throttle change



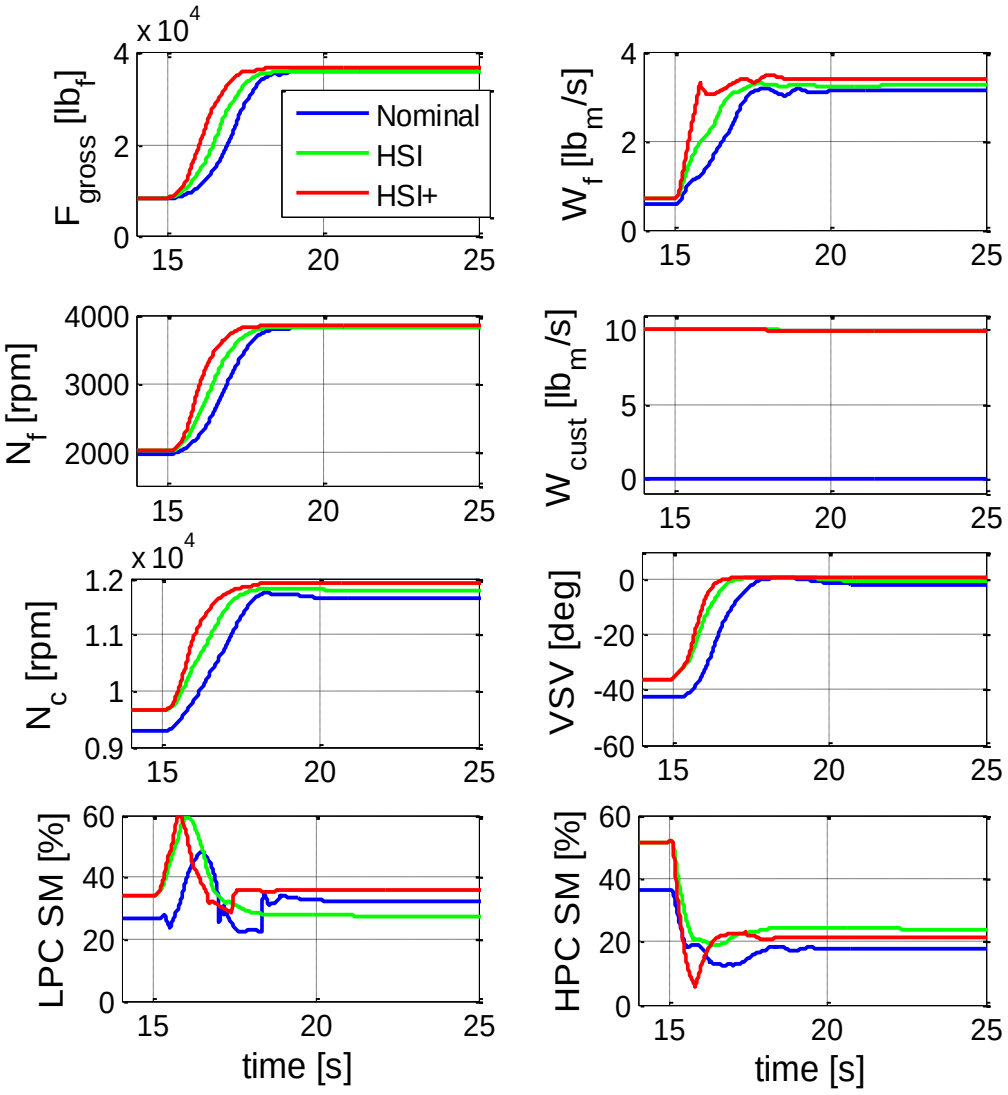
# High Speed Idle

- Designed to improve engine response during approach
- To safely increase engine acceleration we must operate in a region where HPC surge is not as much of a concern
  - Operate at higher shaft speeds
  - Reduces the potential fan/core mismatch
  - Higher speeds lead to more thrust
- During approach/landing it is critical to balance the aircraft's energy
- Engine can be operated in an off-schedule manner to reduce excess thrust
  - Move compressor vanes off-nominal
  - Bleed air from engine components
  - Extract power from shafts
  - etc

# High Speed Idle

- Increase engine idle setpoint
- Reduce excess thrust
  - Move VSV -5$^{o}$ (serves to shift HPC speed lines to the left)
  - Bleed air from core to airframe using customer bleed
  - Close VBV
- Can relax accel limit due to higher steady-state HPC SM (HSI+)
- Increase in thrust (3.7%)
- Increase in fuel consumption (24.2%)

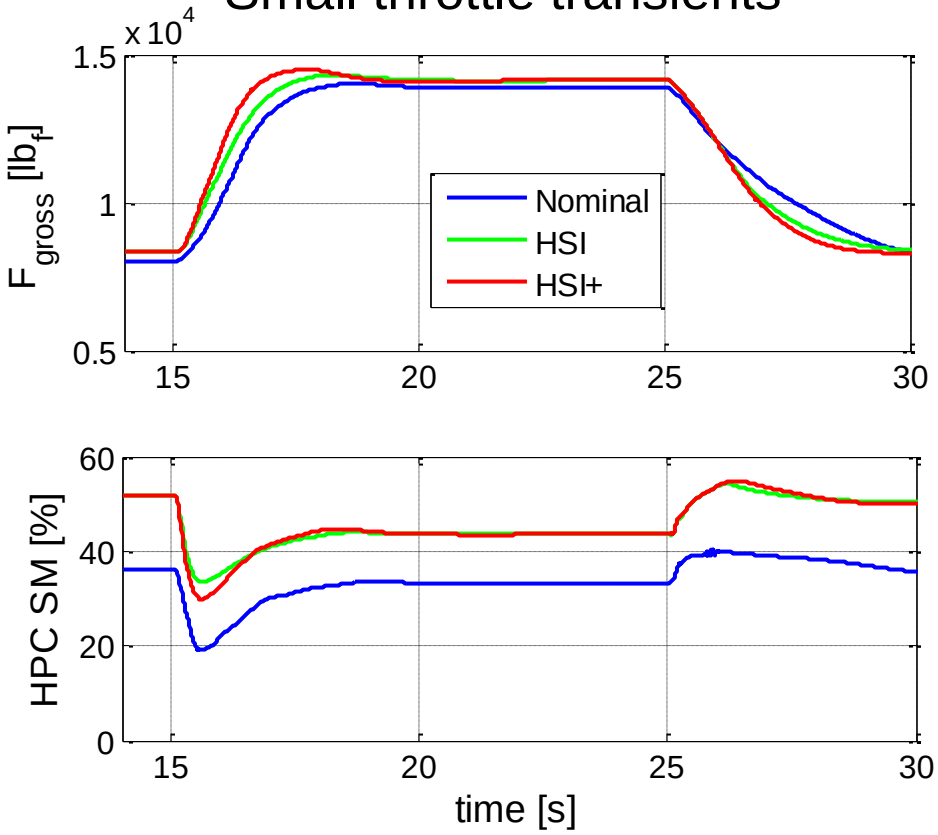
| Control Law | Time Constant |
|---|---|
| Nominal | 2.28 s |
| HSI | 1.81 s |
| HSI+ | 1.36 s |



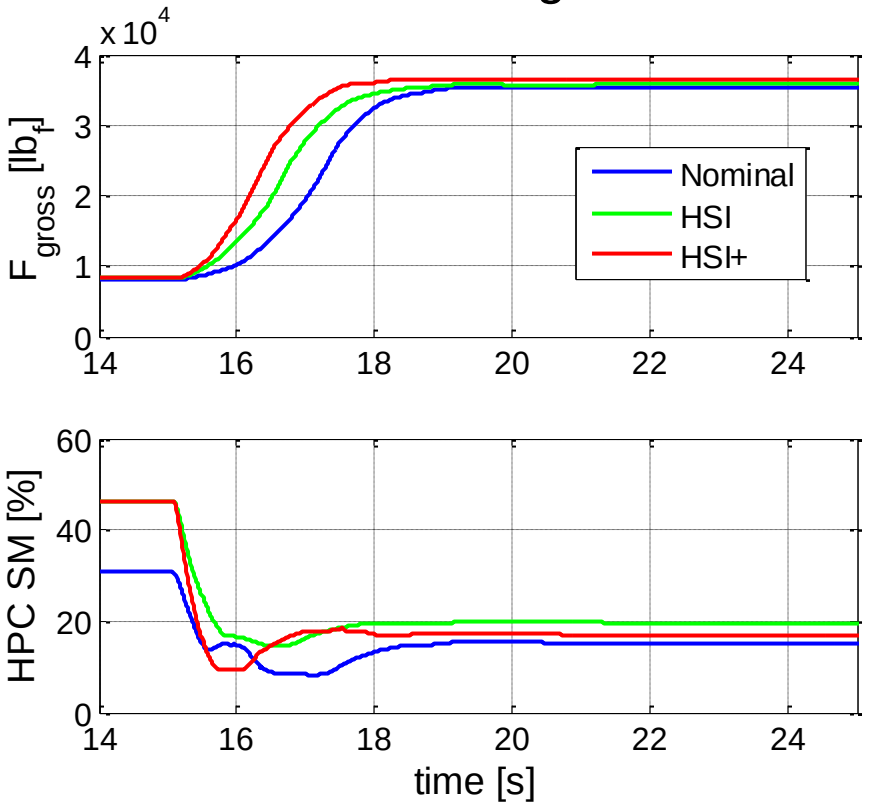
# High Speed Idle

- Same trends and response improvement observed for:

Small throttle transients




End-of-life engines

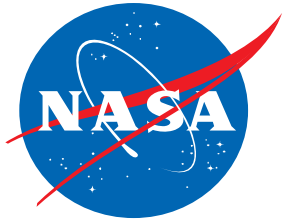


# Conclusions

- It is possible to improve response of C-MAPSS40k with only changes to gains and limits, and by using existing actuators in novel ways.
- Any change will increase the risk of engine failure
- May be acceptable in emergencies if improvement in performance results in increased survivability of aircraft

# Related NASA Publications:


- Guo, T.-H, and Litt, J.S., “Risk Management for Intelligent Fast Engine Response Control,” AIAA-2009-1973, AIAA Infotech@Aerospace Conference, Seattle, WA, April 6-9, 2009.
- Csank, J., May, R.D., Litt, J.S., Guo, T-H., "A Sensitivity Study of Commercial Aircraft Engine Response for Emergency Situations," NASA TM-2011-217004.
- Csank, J.T., Chin, J.C., May, R.D., Litt, J.S., Guo, T-H., "Implementation of Enhanced Propulsion Control Modes for Emergency Flight Operation," AIAA-2011-1590, AIAA Infotech@Aerospace Conference, St. Louis, MO, Mar 29-31, 2011.
- Csank, J., May, R.D., Litt, J.S., Guo, T.H., "The Effect of Modified Control Limits on the Performance of a Generic Commercial Aircraft Engine," AIAA-2011-5972, 47th AIAA Joint Propulsion Conference & Exhibit, San Diego, CA, July 31-Aug 3, 2011.
- May, R.D., Csank, J.T., Guo, T-H., Litt, J.S., "Improving Engine Responsiveness during Approach through High Speed Idle Control," AIAA-2011-5973, 47th AIAA Joint Propulsion Conference & Exhibit, San Diego, CA, July 31-Aug 3, 2011.
- May, R.D., Lemon, K.A., Csank, J.C., Litt, J.S., Guo, T-H., "The Effect of Faster Engine Response on the Lateral Directional Control of a Damaged Aircraft," AIAA-2011-6307, AIAA Guidance, Navigation, and Control Conference, Portland, OR, Aug 8-11, 2011.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